Process Modeling of Large Amplitude Internal Waves in the South China Sea

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LONG-TERM GOALS

My long-term objectives are to develop and employ numerical techniques to enhance our physical understanding of the life-cycle of energetic oceanic internal waves as well as our ability to predict the spatial and temporal variability of the induced flow fields. This goal encompasses the generation, long-range propagation and ultimately, the decay of such waves, either by shoaling or through energy transfer to other waves or modes of motion.

OBJECTIVES

My immediate objectives are twofold: (i) to assess and quantify the numerical requirements for simulation of NLIW evolution, including intensification and degeneration into packets, as they propagate in the nearly inviscid limit over distances comparable to the South China Sea basin and (ii) to validate the approach of combining numerical methods of high accuracy with an immersed boundary method to simulate the generation of internal waves produced by tidal flow over steep isolated sills as occur for example in the Luzon Strait.

APPROACH

To address item (i), simplified experiments were run in which wave generation was idealized using a localized near-surface body force. Waves excited at tidal frequency at energy levels comparable to observations in Luzon Strait and the SCS basin. The waves were then allowed to propagate freely across the deep basin. Given the approximate scales for such waves in the SCS, a scaling analysis of the governing equations, showing a near balance between nonlinear steepening and non-hydrostatic dispersion, was used as a basis for estimating the maximum allowable numerical errors in the various terms in the equations of motion to avoid contamination over the time required for such waves to traverse the basin. Simulations were then carried out using different numerical differentiation schemes with varying formal levels of accuracy on grids of varying resolution in an effort to discern the grid requirements for the different numerical approaches. To address (ii), a series of idealized experiments in which a time-periodic flow of uniformly stratified fluid was forced over an isolated obstacle were carried out. The primary experimental parameters were the degree of nonlinearity of the forcing (measured by the ration of the particle excursion length to the half-width of the sill) and the slope criticality parameter, i.e. whether the downward branches of free waves at the forcing frequency point into the topography (subcritical topography) or into the fluid (supercritical topography). These

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14. ABSTRACT
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simulations were designed to complement and carefully compared with PIV results from the laboratory experiments of Peacock, Echeverri and Flynn at MIT (also under ONR NLIWI support).

WORK COMPLETED

Both sets of experiments have been completed and analyzed. Manuscripts have been written and are under internal review. The first will be submitted to Ocean Modeling and the second to the Journal of Fluid Mechanics. A new set of experiments has been initiated which look at the wave generation process in detail for more realistic stratification (thin, highly stratified surface layer overlying weaker stratification below) at much higher values of the nonlinearity parameter. I am collaborating with Larry Army at SIO on these experiments.

RESULTS

Accuracy requirements were quantified for simulation of nonlinear wave packets over basin scales. Whether or not such waves are represented numerically in a physically reasonable manner is shown to be highly scale-dependent and intrinsically coupled to the discretization methods employed as well as the time and space scales of interest. For ocean basin-scale propagation, as considered here, physically meaningful resolution of these waves demands not only a high degree of overall numerical accuracy but also a careful consideration of the behavior of the explicit but a-physical dissipation operator employed. The introduction of such an operator is an unfortunate necessity. One would like to capture the dynamics at all discrete scales in the inviscid limit but cannot in the face of significant nonlinearities that transfer energy to small scales. At best, we can hope for a calculation in which the scales of interest are treated in a demonstrably nearly adiabatic limit while confining the effects of the dissipation operator, over the time scales of interest, to spatial scales that exist on the given numerical grid but must be considered unresolved in the context of the physics. The experiments for different numerical methods at different grid resolution show the feasibility of achieving these goals using different approaches.

From a technical perspective, good agreement was demonstrated between experimentally measured flow fields using PIV and numerically generated fields combining high-order numerical schemes with an immersed boundary approach. The fields were decomposed into vertical modes and radiation fluxes computed. Results from both methods were compared with the linear theoretical predictions of Petrelis, Llewellyn-Smith and Young (2006).

The more nonlinear, nonuniform stratification experiments are still in the early stages but we are simulating flows very reminiscent of the Knight Inlet observations in which packets of steep waves propagate upstream from the sill prior to the reversal of the tidal currents.

IMPACT/APPLICATIONS

Potential impacts include an objective framework to discuss and assess the performance of different classes of numerical models for the generation and long-range propagation of NLIWs.

RELATED PROJECTS

Internal wave generation in the laboratory (NLIWI), Prof. Thomas Peacock. Described above.

PUBLICATIONS

Density Stratification, Turbulence, but How Much Mixing? G.N. Ivey, K. B. Winters, and J. R. Koseff, Annual Review of Fluid Mechanics Vol. 40: 169-184 (Volume publication date January 2008) (doi:10.1146/annurev.fluid.39.050905.110314) [published, refereed]

Growth of Inertia-Gravity Waves in Sheared Inertial Currents, Winters, K. B. (2008), J. Fluid Mech. 601 , 85 – 100
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